DOE/OE Transmission Reliability Program

Analysis of Multi-terminal HVdc Systems

Harold Kirkham
Pacific Northwest National Laboratory
harold.kirkham@pnnl.gov

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Project Objective

- This has been a startup effort, based on recognition that
  - ac lines exist
  - ac networks exist
  - dc lines exist
  - dc networks do *not* exist. DC systems are point-to-point*
  - The advantages of dc apply to networks as well as point-to-point
  - The advantages of networks apply to dc as well as ac
  - It just makes sense to look at what one could "do" with such a thing as a dc network, assuming you could build one

	ac	dc
pt-pt	✓	✓
net	✓	

* There are now three exceptions of the ~180 that have been built

What are the advantages?

- DC is cheaper to own for high-power long distance transmission
- Networks offer much greater reliability (redundancy) than point-to-point connections
- Why are there no dc networks?
  - The economics of going from 2 terminals to 3 is not good: equipment utilization factor must suffer, or system flexibility
  - In a flexible network not all equipment is fully loaded all the time
  - There are some technical obstacles to making a dc network (breaker?)

- But with the new voltage sourced converters, the problems are most likely solvable

Project result

- We wrote a report on the technology and possible applications for a future dc networked transmission system
- The see the report as increasing “comfort level” for dc grids, and preparing the reader for what they had to offer long-term
- We showed that multi-terminal HVdc systems are both *advantageous* and *feasible*

Title: **An Introduction to High Voltage dc Networks**

Harold Kirkham, Marcelo Elizondo, Jeff Dagle

Report Outline

- Table of Contents of the Report:

  - **Defining the Question**
  - **Applications**
  - **Aspects of the System Problem**
  - **Summary and Conclusions**

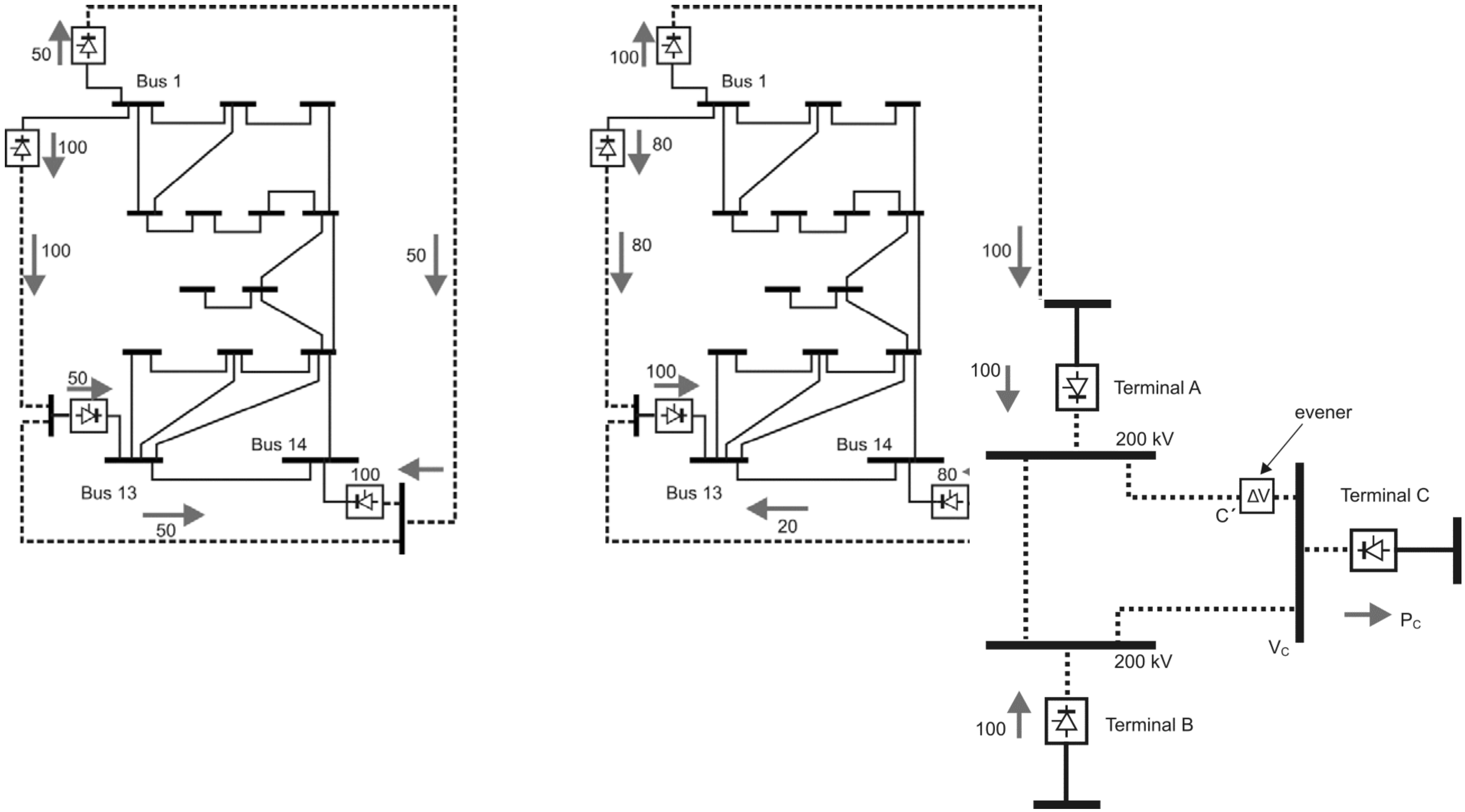
  - Appendix A. History of HVdc technology
  - Appendix B. HVdc in China
  - Appendix C. Protection
  - Bibliography

The next few slides will expand on these topics

from the Report

- Section 1
  - **Defining the Question**
    - Introduction to HVdc and Networks
    - Advantages of VSC systems
    - Multiterminal dc networks
    - Wrap-up: the feasibility of dc networks

dc lines *vs* dc network



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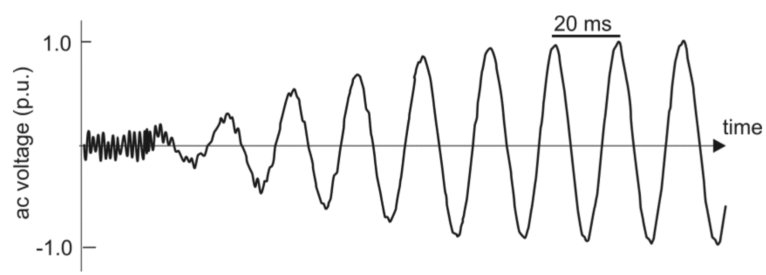
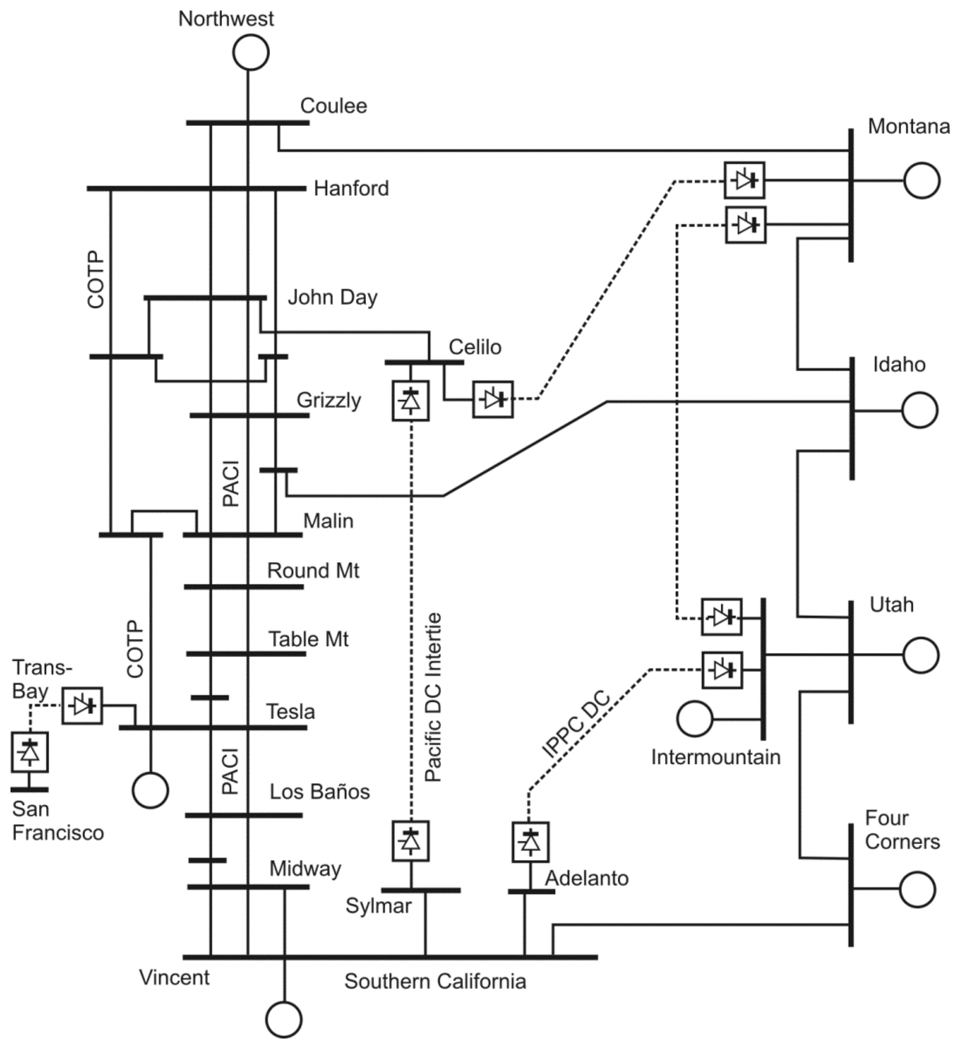
- Section 2
  - **Applications**
    - Supply to Urban Load Centers
    - Interconnection to Offshore Generation
    - Overlay Grid
    - Restoration after Blackout
    - Power Distribution



Western Interconnection



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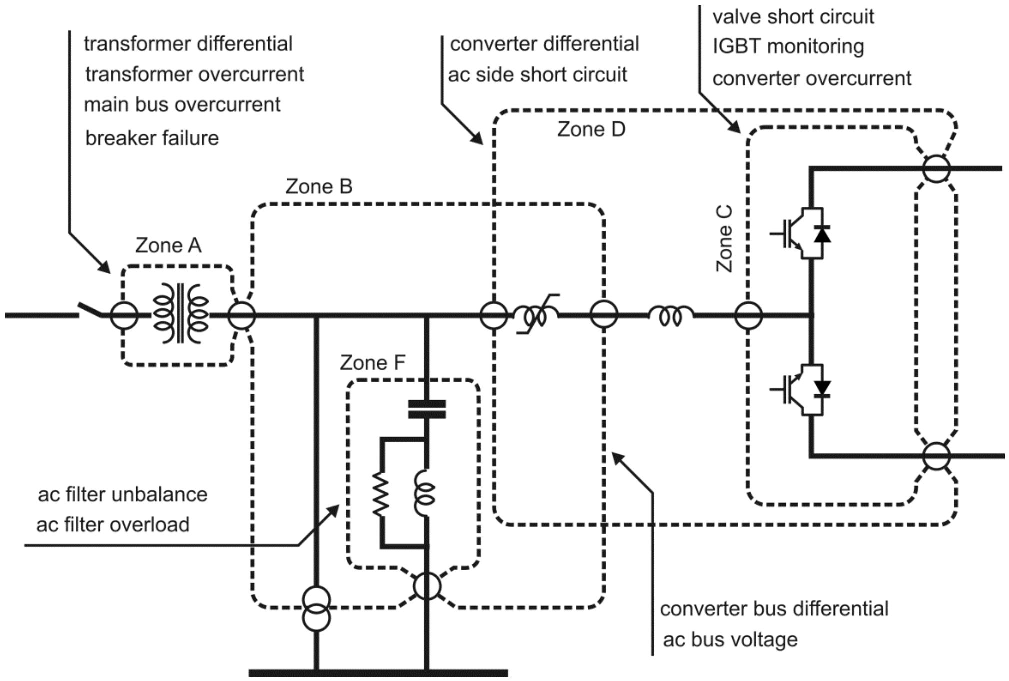
- Section 3:
  - **Aspects of the System Problem**
    - Control of HVdc Networks
    - Modeling Needs
    - Communications
    - Protection
    - High Voltage Insulation

Protection for ac/dc converter



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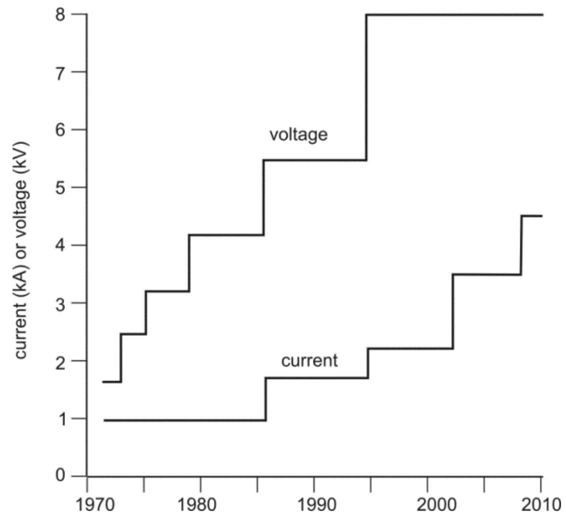
- Appendix A
  - **History of HVdc technology**
    - HVdc Converter/System overview
    - Technology of direct current systems
    - HVdc ratings

Silicon capability



Large ac/dc converter

from the Report

- Appendix B
  - **HVdc in China**
    - Overview
    - Multiterminal Systems

Chinese installed dc systems . . .

description	Voltage, kV	Power, MW	Commission date
Geshouba-Shanghai	±500	1200	1989
Tienshengqiao-Guangdong	±500	1800	2001
Three Gorges-Changzhou	±500	3000	2003
Three Gorges-Guandong	±500	3000	2004
Three Gorges-Shanghai	±500	3000	2006
Guiyang-Guangdong	±500	2 × 3000	2007
Gaoling BTB (1)	±150	2 × 750	2008
Linbao BTB (1)	±120	360	2009
Yunnan-Guangdong	±800	5000	2009
Xiangliaba-Shanghai	±800	6400	2009
Heihei BTB	±125	750	2009
Linbao BTB (2)	±160	750	2009
Deyang-Baoji	±500	3000	2010
Hulunbuir-Lioning	±500	3000	2010
Gaoling BTB (2)	±150	2 × 750	2011
Jingzhou-Shanghai	±500	3000	2011
Ningxia-Shandong	±660	4000	2011
Qinghai-Tibet	±400	1200	2012
Jinping-Sunnan	±800	7200	2012
Nan'ao-Guandong	±160	200	2013

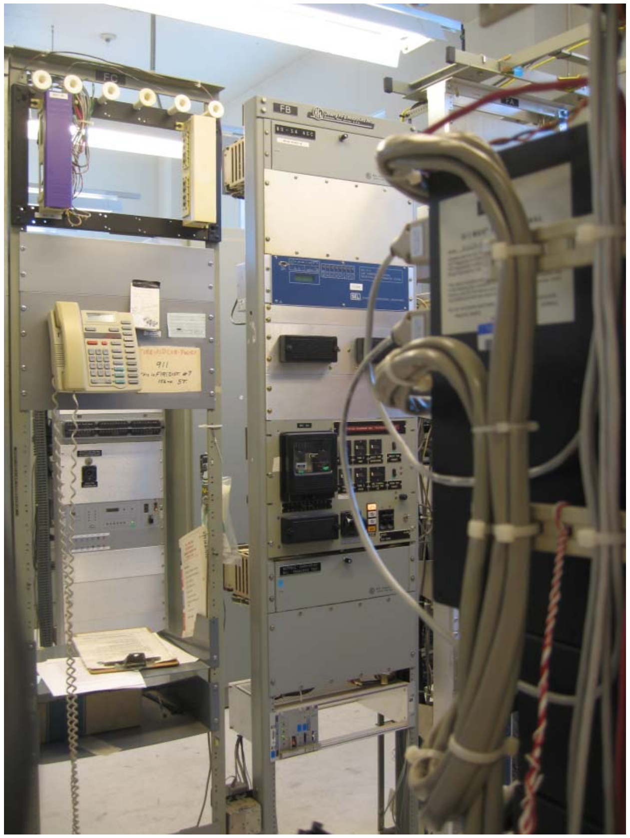
. . .and some future ones:

description	Voltage, kV	Power, MW	Commission date
Hami-Zhengzhou	±800	8000	2013
Xilodu-Zhexi	±800	8000	2014
Ningdong-Zhexi	±800	8000	2015
Zhoushan-Zheijang	±200	400/300/100/100/100	2014
Xianmen-Fujian	±320	1000	2015
Dialian-Liaoning	±320	1000	2018

from the Report

- Appendix C
  - **Protection**
    - Distance Protection
    - Protection: Concluding Remarks

The mixed-technology reality of protection



from the Report

- Bibliography
  - About 45 references
  - Mostly IEEE papers
  - Six CIGRE Reports

Looking Forward

- Thoughts on follow-on work that should be considered for funding in FY14 and beyond:
- Follow-on ideas more focused (now the case is made)
  1. Resume the work. Concentrate on control problems in a mixed system. This would go hand-in-hand with model development. Collaborate with WECC?
  2. Consider islanding control questions in depth. Link to PMU applications?
  3. Extend to consider protection in more depth. This is the topic of an IEEE PES working group, and is very challenging